STATEMENT OF

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BEFORE THE

**HOUSE GOVERNMENT REFORM COMMITTEE
SUBCOMMITTEE ON NATIONAL SECURITY, EMERGING THREATS, AND INTERNATIONAL RELATIONS**

U.S. HOUSE OF REPRESENTATIVES

**“FOLLOWING TOXIC CLOUDS:
SCIENCE AND ASSUMPTIONS IN PLUME MODELING”**

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INTRODUCTION

Chairman and Distinguished Committee Members, I am honored to appear before your Committee again to address your questions regarding the Department's efforts to model chemical, biological, radiological, and nuclear (CBRN) weapons effects. I am Dr. Anna Johnson-Winegar, the Deputy Assistant to the Secretary of Defense for Chemical and Biological Defense, DATSD(CBD). In this role, I am responsible for the oversight and coordination of the Department of Defense Chemical and Biological Defense Program. In addition, until recent organization changes, I have served as the authority within the Department for the accreditation of all common use chemical and biological defense models. I will elaborate on my roles and responsibilities in my testimony today. First, I will provide an overview of modeling in general to address some of the uncertainties that are inherent in all models. I will then also address several questions and concerns regarding the modeling and the supporting methodologies and analyses of events related to the 1991 Gulf War and post-war activities in Iraq. Following my comments, I welcome any questions the Committee may have and I will do my best to answer them.

OVERVIEW OF CHEMICAL AND BIOLOGICAL MODELS

As the mathematician Alfred Whitehead stated, "There is no more common error than to assume that, because prolonged and accurate mathematical calculations have been made, the application of the result to some fact of nature is certain."

All models and simulations are designed for specific purposes. Models are used for hazard prediction, risk analysis, operational decision support, virtual prototyping, weather forecasting, and numerous other purposes. In addition, they also range from simple, user-friendly models to complex models requiring expert users and support staff. No model is suitable for all purposes. Conversely, only select models are appropriate for supporting specific analyses. As examples, the DoD Chemical Biological Defense Program had a specific model developed to predict the hazard resulting from Chemical or Biological weapons used against US forces. The Defense Threat Reduction Agency (DTRA) developed a similar model to predict hazards resulting from U.S. Forces using conventional weapons against an enemy's weapons of mass destruction (WMD) manufacturing capability or stockpiled weapons. The National Center for Atmospheric Research has developed one of several modeling capabilities to predict environmental effects of pollutant releases. These models have many similarities, yet each was developed for specific purposes.

Models, however, are but a small part of any analytical and decision making process. While the selection of the analytic tool must be made in context with the decision process that it will support, the actual efficacy of any model must begin with data or source terms. For a model to represent an event accurately, knowledge about the event is essential. For CBRN effects analysis, key information needed includes weather conditions (such as temperature, humidity, wind speed, cloud cover), geographic conditions (such as topology, structures, type of vegetation), type of chemical or biological threat agent, state of agent (liquid, solid, vapor, binary agent, and types of stabilizers, buffers, etc.), type of delivery systems (e.g., spray tanks, artillery, rockets, submunitions, etc.), and type of event (e.g., dispersal from bulk storage as a result of counterforce operations, unconventional sources, toxic material accidents, etc.) Uncertainty in these areas directly affects the accuracy of model outputs.

Once source terms are defined, models may calculate submunition and debris dispersal and propagation and vapor, liquid, solid, or aerosol transport and diffusion (T&D). This is what the community typically refers to as T&D modeling. T&D of particles is only part of the overall equation. T&D incorporates interaction of the agent with the atmosphere and with the surfaces on which agents are dispersed. Once agents are dispersed, analyses are required to determine the interactions between the agents and the environment and—perhaps most critically—to determine the interactions between the agents and humans. It is not sufficient to determine the quantity of agent to which an individual is exposed; the effects on humans must be calculated. Effects may range from no observable effects to lethal effects and everything in between. Effects may be acute or chronic, and the response times may be immediate or delayed. A critical factor leading to uncertainty in models is the limited dosage data on human exposure to chemical or biological warfare agents. Effects of human exposure are primarily extrapolated from animal tests along with analysis of some limited accidental exposures.

All of these factors result in some degree of uncertainty in the output from <u>all</u> models. The role of models is to provide tools to the analyst, who uses the output from the models to support decision-making. The analyst will incorporate risk assessments, sensitivity analyses, and trade-off analyses to account for uncertainty and to provide the most reasonable response germane to the question posed by the decision maker to answer a question.

I will now address the specific questions asked by the Committee.

1. How were possible chemical warfare agent releases modeled in determining potential exposures in the Persian Gulf War?

A. Background

In 1996, the Central Intelligence Agency (CIA), in response to a request of the Presidential Advisory Committee on Gulf War Veterans' Illnesses, reported on computer modeling it had used to simulate possible releases of chemical warfare agents from several sites. (Modeling was necessary because there had been no measurements of such releases at the time of the war.) Because the CIA used only a single model approach, its results reflected the strengths and weaknesses of only that model. On November 2, 1996, to improve computer modeling over the earlier CIA results, the DoD asked the Institute for Defense Analyses (IDA) to convene an independent panel of experts in meteorology, physics, chemistry, and related disciplines. The panel reviewed previous modeling analyses and recommended using multiple atmospheric models and data sources to generate a more robust result than that produced by a single model. Specifically, it stated, "the combination of using more than one model and of varying the inputs provides a comprehensive approach to understanding the uncertainties contributed by the reconstruction of the meteorology...." The Special Assistant for Gulf War Illnesses agreed to conduct a new modeling effort to implement this recommendation.

To implement the recommendations of the IDA panel, the DoD and CIA asked other agencies with extensive modeling experience to participate in the modeling process. The modeling team consisted of scientists from the Defense Threat Reduction Agency (DTRA); the Naval Research Laboratory (NRL); the Naval Surface Warfare Center (NSWC); the National Center for Atmospheric Research (NCAR); and Science Applications International Corporation (SAIC) (supporting the CIA and DTRA). The purpose of this modeling effort was to identify geographical areas that could be used with population location information to identify two sub-groups: one group who was "possibly exposed" and a second group who was highly unlikely to have been exposed, or in shorter words, "not exposed". Whenever an analytical effort uses multiple methods or tools, we want to see agreement so we can gain confidence from that agreement. When agreement does not occur, as was the situation in this case, we must either choose one result as the most reasonable or the worst case or we must combine the differing results.

In this case, the analyst team decided to combine the model results by taking the union of all the "possibly exposed" areas from all the models. This decision was valid for two reasons: First, this method is the best for identifying everyone who was "possibly exposed" and second, this method produces two groups appropriate for the subsequent epidemiology studies. To believe this method produces two groups appropriate for epidemiology studies, the team did not have to believe everyone was correctly put in the right group, the team only had to believe that most of the truly exposed were in the "possibly exposed" group and very few of the truly exposed were in the "not exposed" group. The analyst team was confident that they accomplished this.

B. Methodology

The DoD adopted the IDA panel recommendation to use an ensemble of weather and dispersion models combined with global data sources to assess the possible dispersion of chemical warfare agents. The methodology for modeling the release of agent was a process that used:

- A source characterization to describe the type and amount of agent released, and how rapidly it discharged. (The CIA provided the source characterization assessments.)
- Data from global weather models to simulate global weather patterns.
- Regional weather models to simulate the weather in the vicinity of the suspected agent release. (Since Iraq stopped reporting meteorological observations to the World Meteorological Organization in 1981 during the Iraq-Iran war, and since very limited onsite meteorological data were archived by the coalition forces during the 1991 Persian Gulf War, the necessary meteorological data for dispersion calculations were best simulated by state-of-the-art mesoscale meteorological models, such as COAMPS (Coupled Ocean-Atmospheric Mesoscale Prediction System), MM5 (National Center for Atmospheric Research/ Penn State Fifth Generation Mesoscale Model), and OMEGA (Operational Multiscale Environmental Model with Grid Adaptivity). These peer-reviewed and highly sophisticated models are routinely used to forecast weather.)
- Transport and dispersion models (often simply called dispersion models) to project the possible spread of the agent as a result of the simulated regional weather. (In a November 22, 1996 memorandum of the Office of Assistant to the Secretary of Defense for Nuclear and Chemical and Biological Defense Programs, Deputy for Chemical/Biological Matters, and Deputy Under Secretary of the Army (Operations Research), HPAC (Hazard

Prediction and Assessment Capability) and VLSTRACK (Chemical/Biological Agent Vapor, Liquid, and Solid Tracking Computer Model) were identified as the preferred dispersion models for DOD applications. Therefore, these two models were selected to predict dispersion patterns of the potential warfare agent releases, with meteorological inputs to be provided by the above three meteorological models.)

- A database of Gulf War unit locations to plot probable military unit locations in relation to the hazard area and estimate possible exposures. The effort to plot probable locations was not part of the modeling per se, but was an analysis required to project possible exposures.

The methodology used two types of models: weather models and dispersion models. The weather models allowed us to simulate the weather conditions in specific areas of interest by approximating both global and regional weather patterns. Based on the weather generated by a global model, a regional weather model predicted the local weather conditions in the vicinity of a possible chemical warfare agent release. Both the global and regional weather models were supplemented by actual, although quite limited, weather measurements from the Persian Gulf and surrounding regions.

The dispersion models allowed us to simulate how chemical warfare agents may have moved and diffused in the atmosphere given the predicted local weather conditions. These models combined the source characteristics of the agent—including the amount of agent, the type of agent, the location of the release, and the release rate—with the local weather from the regional models to predict how the agent might disperse. Running one dispersion model with the weather conditions predicted by each regional model resulted in a prediction of a unique downwind hazard area. Running each dispersion model with the weather from each of the different regional weather models resulted in a set of unique hazard areas. These hazard areas were overlaid to create a union, or composite, of the various projections. The composite result provided the most credible array of potential agent vapor hazard areas for determining where military units might have been exposed. This was the basic process for all of our modeling efforts.

The entire modeling process was repeatedly reviewed by government and independent experts in the field. A final academic peer-review was completed before publishing results of the modeling.

2. What models were used?

Based on several criteria, the Department used a collection of atmospheric models to assess the possible dispersion of chemical warfare agents. The IDA panel recommended basic criteria for model selection, including using high-resolution mesoscale meteorological models and transport and dispersion models that accept temporally and spatially varying meteorological fields. The IDA panel also recommended DoD use models currently sponsored by various organizations under DoD and the Department of Energy to perform additional modeling analyses. Three mesoscale meteorological models (COAMPS, MM5, and OMEGA) and two dispersion models (HPAC and VLSTRACK) were used. These models clearly did not represent all available models. However, they had all been peer reviewed, validated, and extensively used by the DoD and scientific communities.

Initially the Naval Research Laboratory (NRL) teamed with the Naval Surface Warfare Center (NSWC) to link the COAMPS meteorological model and the Vapor, Liquid, Solid

Tracking (VLSTRACK) dispersion model. The Lawrence Livermore National Laboratory (LLNL) Atmospheric Release Advisory Capability (ARAC) operated the Mass-Adjusted Three-Dimensional Wind Field (MATHEW) diagnostic meteorological model linked with the Atmospheric Dispersion by Particle-in-cell (ADPIC) dispersion model. Finally, DTRA ran the OMEGA prognostic meteorological model linked to the (Hazard Prediction and Assessment Capability/Second-Order Closure Integral Puff (HPAC/SCIPUFF) dispersion model. In addition, responding to the IDA panel's suggestion to include an established civilian mesoscale model to provide comparative results, the NRL obtained 48 hours of meteorological reconstruction generated by the MM5 mesoscale model from NCAR. Comparisons among MM5, COAMPS, and OMEGA indicated that these models produced similar reconstructions of the meteorology.

The IDA panel, chaired by Gen. (Ret.) Larry Welch and consisting of renowned scientists in the fields of meteorology and atmospheric dispersion, reviewed LLNL's initial modeling efforts, together with the initial modeling results given by COAMPS, OMEGA, HPAC, and VLSTRACK. (The MM5 mesoscale meteorological model had not been applied at that time.) The IDA panel found that while the agent transport based on both the COAMPS and OMEGA meteorological model results showed a general direction towards the west, that based on the MATHEW meteorological model results showed a general direction towards the east. A review of modeling methodologies by the IDA panel suggested that the coarse meteorology (2.5 by 2.5 degrees, or roughly 250-km resolution) used by MATHEW failed to resolve the important mesoscale features and the atmospheric boundary layer due to a lack of sufficient observational data. As a result, in its July 9, 1997 report to the DoD, the IDA panel stated it viewed LLNL's MATHEW model as less capable because it modeled atmospheric phenomena with less fidelity. The COAMPS and OMEGA results were later corroborated by another meteorological model, MM5. Another important difference between MATHEW and models such as COAMPS, MM5, and OMEGA is that the former is a "diagnostic" model, while the latter are "prognostic" models. Prognostic models are based on fundamental conservation laws of mass, momentum, and energy, and can be used to forecast weather. Diagnostic models mainly interpolate between existing data, and thus cannot be used to forecast weather. As a result, the LLNL's models were not further considered.

After the initial work performed in response to the IDA panel recommendations, the DoD established linkages between mesoscale meteorological models and dispersion models:

- MM5 → HPAC/SCIPUFF
- COAMPS → HPAC/SCIPUFF
- COAMPS → VLSTRACK
- OMEGA → HPAC/SCIPUFF

3. What were the strengths and weaknesses of the models?

The three mesoscale meteorological models (COAMPS, MM5, and OMEGA) are all quite comprehensive in treating atmospheric physics and thermodynamics. They all have been well tested in simulating atmospheric flows such as hurricanes, frontal passages, land and sea breezes, and snowstorms. This type of weather models represents the best available tools to simulate weather in the absence of onsite measurements. Areas of improvement for these models include better assimilation of high-resolution land use, soil moisture, and terrain data; better treatment of urban areas; and better quantification of model uncertainty.

OMEGA, COAMPS, and MM5 have much in common: all are three-dimensional, primitive-equation, mesoscale models solving the non-hydrostatic, compressible form of the dynamic equations and use many of the same parameterizations of physical processes (e.g., surface fluxes and moist convection).

However, these models have different features. For example, COAMPS and OMEGA are used in an operational setting, so operational constraints balance features related to data input/output considerations and objectives such as physical fidelity and numerical accuracy. As an example, COAMPS and OMEGA process observational data and perform quality control in a fully automated fashion. Conversely, MM5 is mostly used in research applications and thus contains numerous optional physical algorithms.

MM5 is widely used in research communities, COAMPS is the operational prediction model for the Navy and DoD. The basic equations of both models are based on the work of Klemp and Wilhelmson.[1] Both models use a staggered grid both horizontally and vertically. Grid nesting efficiently treats a wide range of temporal and spatial scales. On the other hand, the OMEGA grid is unstructured horizontally and adapts to both underlying surface features and dynamically evolving atmospheric phenomena. This approach achieves local accuracy of the numerical solution with a single, non-uniform grid and does not require communication between separate nesting grids.

To handle fast-moving acoustic modes and slower-moving meteorological modes, COAMPS and MM5 follow Klemp and Wilhelmson's general time-splitting algorithm. The slower modes include terms such as horizontal advection and the Coriolis force. Due to the significantly finer vertical grid spacing than horizontal spacing, semi-implicit schemes are used for integration. OMEGA's unstructured grid environment locally adapts time steps to the grid structure to satisfy a local Courant-Friedrichs-Lewy constraint, thereby increasing computational efficiency. In addition, OMEGA treats acoustic waves by applying an explicit horizontal filter and a semi-implicit vertical filter.

The planetary boundary layer (PBL) is a critical factor in controlling mesoscale weather systems. Because of the large fluxes of heat, moisture, and momentum near the earth's surface, there is generally an agreement on the need for high-resolution treatment of the physics of this layer. However, the three models apply different approaches to modeling the PBL. COAMPS and OMEGA apply a fine vertical resolution to resolve the PBL, including the stable boundary layer. In addition, they apply the level 2.5 PBL model developed by Mellor and Yamada.[2] The crucial phenomenon to resolve is the transport of mass and momentum in the PBL by large energetic eddies. Traditional local-gradient methods cannot adequately treat such a well-mixed atmosphere. Mellor and Yamada's higher-order closure methods, though computationally expensive, are capable of representing a well-mixed boundary layer. On the other hand, the lowest MM5 model computation level is approximately 40 m above ground level, with increasing layer depths above, so it is difficult for the model to properly resolve the shallow nocturnal PBL. Local-gradient theory may fail because it does not account for the influence of

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[1] Klemp, J.B. and R.B. Wilhelmson, 1978: The simulation of three-dimensional convective storm dynamics. *J. Atmos. Sci*. **35**, 1070–1096.

[2] Mellor, GL and T. Yamada, 1974: A hierarchy of turbulent closure models for planetary boundary layers. *J Atmos Sci*., **31**, 1791-1806.

large eddy transports and does not treat entrainment effects. MM5 uses non-local atmospheric boundary layer schemes that are more effective for coarser grids.

The PBL's spatial variability can result from a range of mechanisms, including topographic elevation variation, land-and-sea breeze circulation, and local contrasts in physical properties at the desert surface.

Since the model simulations' objective was to best analyze the area's meteorological conditions, use of a four-dimensional data assimilation or hindcasting was crucial. Although grid structures, numerical solvers, and PBL parameterizations all contribute to different model features, the most significant difference among the three mesoscale models is probably in their data assimilation strategies. COAMPS assimilates observations intermittently (every 12 hours) on all three grids using its previously forecasted fields as the first-guess fields. In other words, the model stops at 12-hour intervals during integration, uses the model fields as a background to generate a new objective analysis, and then restarts for the next integration period. Each restart incorporates fresh data to limit error growth. On the other hand, MM5 applies Newtonian relaxation, which gradually drives the model results toward a gridded analysis by including an extra forcing term in each governing equation. Data assimilation is performed on the outermost grid only.

The DoD modeling team used HPAC and VLSTRACK dispersion models to estimate possible hazard areas. The HPAC dispersion model is unique in that it can generate probabilistic outputs, thus providing a measure of uncertainty. The VLSTRACK dispersion model is more traditional, and generates only ensemble-mean results. If the underlying terrain is not flat, HPAC has two procedures available to internally generate mass-consistent wind fields based on the input meteorology. On the other hand, VLSTRACK is less sophisticated, and uses only a simple scheme to interpolate wind fields.

Both VLSTRACK and HPAC/SCIPUFF use the COAMPS wind field; the MM5 and OMEGA fields drive HPAC/SCIPUFF only. Even though the same meteorological fields are used, the ways the dispersion models use them are different. HPAC/SCIPUFF uses a set of artificial profiles by selecting a reduced set (i.e., 400) of horizontal grid locations from the meteorological model grid. HPAC/SCIPUFF then generates a mass-consistent gridded wind field based on refined surface topography. HPAC/SCIPUFF can use the data directly, and thus bypass the mass-consistency calculations, if these data are on a latitude/longitude or UTM grid. However, none of the mesoscale meteorological models used either of the grid systems. The alternative was to interpolate the profiles using the mass-consistency and achieving higher terrain resolution at the same time. VLSTRACK does not have an integrated meteorological model; its three-point interpolation scheme directly uses mesoscale meteorological fields.

Based on the similarity theory, the PBL's mean wind and temperature profiles and turbulence are primarily functions of the surface roughness (z0), boundary layer depth (zi), Monin-Obukhov length (L), and friction velocity (u*). Both HPAC/SCIPUFF and VLSTRACK use standard tables and equations to specify u* and z0 if they are unavailable from the meteorological model outputs.

VLSTRACK and HPAC/SCIPUFF calculate L and zi quite differently. For example, VLSTRACK does not directly calculate or use surface heat flux values (H) in modeling the PBL, but uses the Golder nomogram to establish the primary link between the meteorological conditions (captured by the PG stability class) and the Monin-Obukhov stability characterization.

As described above, HPAC/SCIPUFF specifies the PBL parameters according to the calculation mode (Simple, Observation, or Calculated). For the Observation mode, the model either directly accepts the PBL parameters in the input file or calculates them based on the PG stability class. The latter approach is comparable to the VLSTRACK implementation. The Simple mode consists of very simple diurnally variable formulae. The Calculated mode consists of detailed energy budget methods for determining the surface heat flux and prognostic equations for determining zi, thus over-riding the internal calculations of these two PBL parameters.

VLSTRACK and HPAC/SCIPUFF apply fundamentally different puff dispersion methods. VLSTRACK implements dispersion algorithms adapted from the NUSSE4 Gaussian plume model. These algorithms are derived from the classical Taylor's theory for a continuous source in a homogeneous turbulence field and provide a relationship between cloud dispersion and the velocity fluctuation statistics together with the Lagrangian time scale. The latter two are empirical parameters requiring specification. The generality of the turbulence closure methods used in HPAC/SCIPUFF provides a dispersion representation for arbitrary conditions. However, the practical application of the model requires empirical closure assumptions for higher-order correlation terms, and empirical specification of the velocity and length scales describing the atmospheric turbulence spectrum.

HPAC/SCIPUFF treats phenomena such as puff deformation and concentration fluctuation on a more rigorous theoretical basis. The equation for the concentration fluctuation provides a robust approach to producing probabilistic output. Note that the stochastic uncertainty the HPAC/SCIPUFF methodology estimates includes only contributions due to turbulent fluctuations in the atmosphere. Other sources of uncertainty such as errors in meteorological inputs and in the source term also contribute to the total uncertainty. HPAC/SCIPUFF optionally allows the specification of the meteorological uncertainty in the observational data file. However, these uncertainties were not available for input to HPAC/SCIPUFF.

4. What models would DoD use today should an event occur in a combat theater?

The Department is party to international agreements within NATO to use simplified templates for real time battlefield hazard prediction. The Department also has a limited number of locations that can use one or more of the three DoD Interim Standard Hazard Prediction Models in near real time. For NBC defense against enemy attacks, DoD uses NATO Standardization Agreement (STANAG) 2103/Quadrapartite Standardization Agreement (QSTAG) 187 on Reporting Nuclear Detonation, Biological and Chemical Attacks, and Predicting and Warning of Associated Hazards and Hazards Area. These standardization agreements cover Allied Tactical Publication (ATP)-45, which specifies procedures for hazard area estimation. For hazard areas from chemical or biological attacks on US forces, DoD uses the VLSTRACK model. For allied offensive attacks on enemy WMD targets, DoD uses HPAC. For attacks or incidents on US Chemical Demilitarization Facilities, DoD uses the Emergency Management Information System (EMIS, commonly referred to as D2PUFF). For post event analysis, the Department would perform an analysis similar to that noted in questions one and two.

The Department also has a program that will field a single hazard prediction tool throughout DoD in the near future. For the forensic analysis of a single event or a few events of high interest (as long as time was not an issue) we do as we did before; we would seek out organizations with extensive modeling experience in this area. We would likely use all of those agencies models' unless some aspect of their models' capabilities identified them as unsuitable for the event of interest. One possible starting point could be the August 2002 report by the Office of the Federal Coordinator for Meteorology, *Atmospheric Modeling of Releases from Weapons of Mass Destruction: Response by Federal Agencies in Support of Homeland Security* (FCM-R17-2002). This report identifies 29 models as potentially appropriate for use in support of homeland security.

5. Who decides what model(s) would be used?

For operational use, the Combatant Commander has the ultimate responsibility as to what is used in theater. They receive a variety of advice and guidance from various sources. For allied offensive operations during the most recent two conflicts—ENDURING FREEDOM and IRAQI FREEDOM—commanders used HPAC. In defensive applications, ATP-45 and VLSTRACK were used.

Until a recent organizational change, the DEPSECDEF and the USD(AT&L) had designated my office with this responsibility. With the April, 2003, USD(AT&L) approval of the Implementation Plan for Management of the Chemical and Biological Defense Program, the Assistant to the Secretary of Defense for Nuclear and Chemical and Biological Defense Programs, ATSD(NCB) is named the DoD Modeling and Simulation Executive Agent for M&S representations of chemical, biological, radiological, and nuclear (CBRN) weapons, weapons effects, and countermeasures (except when M&S is used by the test and evaluation community, in which case the Operational Testing Authority and/or the Director of Operational Test and Evaluation is the accrediting authority.) This DoD-wide class accreditation authority is delegated to the Joint Program Executive Office for Chemical and Biological Defense (JPEO-CBD) to oversee and approve all common use CBRN defense models and simulations; certification authority for CBRN defense data; and resolution of validation and certification issues.

6. How has modeling improved since the Persian Gulf War?

There have been numerous technical advances over the past decade in the capabilities of various models. These advances have been integrated into models currently in use to support hazard prediction, operational analyses, and other activities. Each of these advances enhance the realism of the models and enable the models to be used as tools to provide a definitive estimate of the "ground truth" regarding the actual release of chemical or biological threat agents. A summary of enhancements are:

- surface evaporation methodology
- multiple components
- horizontal and vertical cloud splitting (or diagonal)
- mass reflections within the mixing layer and/or planetary boundary layer
- fumigation into mixing layer or planetary boundary layer from above
- use of nested gridded meteorology forecast data (>10,000 locations, 16+ vertical levels, 120 hours at 1 hour intervals, 6 parameter values at each grid point, ~2 GB file size)
- representation of individual stack and/or munition locations
- ability to fix surface flux to agree with measurements

- high altitude source characterization and droplet dynamics
- high altitude meteorology characterization (GUACA, GRAM-95, other)
- eddy diffusivity estimation above the planetary boundary layer
- extension of toxicity from lethal and incapacitating effects to 8 hour workplace and 72 hour threshold exposure levels
- hazard output areas up to 600 km on a side at 5 km spacing
- map projection algorithms for geographic locations
- use of met forecast model turbulence parameters
- output in terms of probability of exceeding a given hazard level
- forest canopy and urban region bulk dispersion effects
- puff centroid rise with distance relation
- vapor deposition algorithms and vapor reaction in the air
- display of hazard contours in a variety of graphical formats, including Arc View

In recognition that a Joint Service plume model was needed to address all DoD uses: defense against enemy attacks, offensive attacks on enemy WMD targets, and attacks or incidents on US Chemical Demilitarization Facilities; DoD has begun work to bring the different modeling efforts together into one DoD acquisition program—the Joint Effects Model (JEM) program. Mature science and technology plume modeling efforts will transition to a program charged with further development, fielding, and sustainment activities. Plume models will be fully integrated into our command and control systems and will benefit from real world intelligence, meteorology, and integration into the common operational picture.

7. What sources of meteorological data are needed for effective plume modeling?

Effective plume modeling includes the integration of meteorological data with topographical, geographic, and related data. These data must be provided with a temporal frequency consistent with the time scale over which the plume modeling is calculated. The basic data needed for plume modeling include:

- wind speed and direction over domain of interest.
- air temperature and relative humidity.
- terrain elevation and land use.

It is best if the wind flow is characterized at multiple vertical levels.

Many observed and derived sources of data can be input directly into plume models. These data provide a better characterization of the boundary layer. Many times, the following data may contribute to more accurate predictions.

- vertical wind speed component positive upwards
- pressure/geopotential height
- ATP45 stability category
- inverse Monin-Obukhov length
- turbulent kinetic energy

- surface heat flux density
- boundary layer depth
- precipitation
- surface conditions
- ground moisture
- visibility
- ceiling (Cloud cover > 5/8)
- cloud cover.

Other weather parameters, although not directly needed by the plume model, are important to the numerical weather prediction model and add accuracy to the values input to the plume model:

- cloud type
- significant weather phenomena
- sea state
- sea swell
- sea surface temperature
- amount of sea-ice
- amount of fast-ice
- sea-ice topography
- sea-ice openings

Basic terminology and data formats for weather terms are defined within the NATO Standardization Agreement (STANAG) 6022, Annex A, “Adoption of a Standard Gridded Data Meteorological Message.” Meteorological data types may include climatological data, numerical weather analysis, numerical weather predictions, observations, or compound data composed of two or more of these types.

As may be evident, there is a significant amount of data that is measured. Not all data are essential for effective plume modeling. There is a constant trade-off in providing the most comprehensive data *versus* timely information *versus* high resolution. Some information can be accurately provided in real time or even predicted with some accuracy. Other data require some time to gather and describe the information accurately. While other data may be gathered accurately and quickly to provide high resolution, but may impose a massive data burden, thus making it useable only to those with access to computers with sufficient processing power. Finally, much of the data may be absent or estimated because of natural variability that could only be described in a qualitative sense (e.g., atmospheric stability may be “very” unstable.) Thus, even with perfect data, there will be uncertainties in an effective model because meteorology is inherently uncertain.

8. How are plume models tested and validated?

Within the DoD, significant and continuing efforts have been undertaken to test and validate plume models at multiple levels in order to provide a high degree of confidence in their output. To establish a common term of reference, we refer to Validation as the process of determining the degree to which a model provides an accurate representation of the real world from the perspective of the intended uses of the model.

To validate plume model outputs, the outputs have been statistically compared to thousands of small and large scale experiments and real world releases covering local, regional, and continental distances. To facilitate validation efforts, the JPEO-CBD maintains a growing database of Validated Test Data to which the models are compared across a range of variables including meteorology, agent persistency, agent toxicity, and various ground surfaces (e.g., grass, concrete). The database contains well-characterized plume information leveraging DoD and other agency investments over a period of approximately 40 years. Agent dissemination methods are validated against field tests of representative dissemination systems. In some cases the method is limited to intelligence of the threat. Lessons learned from ongoing operations, exercises, and Advanced Concept Technology Demonstrations (ACTDs) have also supported plume model validation. Lastly, plume model development is subject to multiple levels of peer reviews and reviews by independent organizations.

Data requirements to validate plume models continue to grow as the modeling requirements expand with the threat. For example, in recent years, limited experiments in urban environments and building interiors have been conducted to improve the understanding of urban wind patterns and to collect data to validate plume models. This summer, a more robust urban test is being conducted to expand our validated test database and to assess urban plume model maturity. Additional Science and Technology efforts are both planned and in progress. Efforts such as the intercept of a ballistic missile filled with agent simulant (planned) and agent persistency on surfaces (in progress) will provide essential data to validate and improve plume-modeling efforts.

To support fielding requirements, further testing of plume models is focused towards showing system effectiveness, suitability and survivability in an operational environment. To that end, Information assurance, Interoperability and Integration testing with Warning and Reporting and service Command and Control systems is planned. Because of the criticality of this area, the Director, Operational Test and Evaluation, has placed our current NBC Joint Warning and Reporting Network (JWARN) program on oversight for operational testing. We are confident that, upon completion, we will have must thoroughly validated and tested hazard prediction capability anywhere.

9. How is plume modeling tied to troop location data?

Plume modeling and troop location data are inextricably linked in order to estimate potential effects of exposures on personnel and mission. Yet, the ability to model plumes to determine hazardous areas is not affected by the location of units. However, the ability to analyze possible exposure of service members in those units to the hazardous contents of plumes often requires plume modeling in the absence of on-site testing. The separate data for plumes and troop location are tied together through the Joint Warning and Reporting Network (JWARN). Personnel and mission effects are then evaluated based upon the time dependent hazard environment and the troop location in that environment. Currently, JWARN troop location and plume data are tied together in a semi-automated manner. Planned upgrades will automate this process.

JWARN Block I is an automated Nuclear, Biological, and Chemical (NBC) Information System. JWARN Block I is essential for integrating the data from NBC detectors and sensors into the Joint Service Command, Control, Communication, Computers, Information and Intelligence (C^4I^2) systems and networks in the digitized battlefield. JWARN Block 1 provides the Joint Force an analysis and response capability to predict the hazards of hostile NBC attacks or accidents/incidents. JWARN Block I will also provide the Joint Forces with the operational capability to employ NBC warning technology that will collect, analyze, identify, locate, report and disseminate NBC threat and hazard information. JWARN Block I is located in command and control centers at the appropriate level defined in Service-specific annexes and employed by NBC defense specialists and other designated personnel. It allows operators to transfer data from and to the actual detector/sensor/network and automatically provide commanders with analyzed data for decisions for disseminating warnings to the lowest echelons on the battlefield. It provides additional data processing, production of plans and reports, and access to specific NBC information to improve the efficiency of NBC personnel assets.

JWARN Blocks II & III completely meet the JWARN requirements for a fully automated CBRN Information System for stationary, vehicular, mobile and dispersed sensor applications that takes data directly from the sensors and generates warning and reporting information directly to the host C^4I^2 system. JWARN Blocks II & III will provide the Joint Force a comprehensive analysis capability with the use of the Joint Effects Model (JEM) which is currently under development to replace our three DoD Standard Interim Hazard Prediction tools. JWARN will also be capable of utilizing the suite of capabilities to analyze operational consequences and perform alternative course of action analyses using the suite of tools to be provided by the Joint Operational Effects Federation (JOEF). JWARN will also provide the Joint Forces with the operational capability to employ evolving warning technology that will collect, analyze, identify, locate, report and disseminate NBC threat and hazard information. JWARN will be located in command and control centers and hosted as a segment on C^4I^2 systems at the appropriate level defined in Service-specific annexes and employed by NBC defense specialists and other designated personnel. The JWARN system will transfer data automatically via hard wire or other means from and to the actual detector/sensor/ network nodes and provide commanders with analyzed data for decisions for disseminating warnings to the lowest echelons on the battlefield. It will provide additional data processing, production of plans and reports, and access to specific NBC information to improve the efficiency of NBC personnel assets.

Thank you for the opportunity to address these issues. I will try to address any additional concerns or questions the Committee may have.